Modified mission planning schemes for the aging CYGNSS mission with expanding scientific pursuits during high beta angle seasons

A.M. Alexander, W. Wells, R. Medina, J. Redfern

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SOUTHWEST RESEARCH INSTITUTE

University of Colorado Boulder

Outline

1. Introduction to CYGNSS mission, science and orbital configuration
2. Increased interest in CYGNSS science since launch
3. Beta angle “seasons” and CYGNSS
4. Updates due to aging spacecraft:
   i. Modified mission planning for beta angle seasons
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CYGNSS, NASA's first Earth Venture Mission

Cyclone Global Navigation Satellite System (**CYGNSS**) launched 8 small spacecraft into Low Earth Orbit with an inclination of 35°

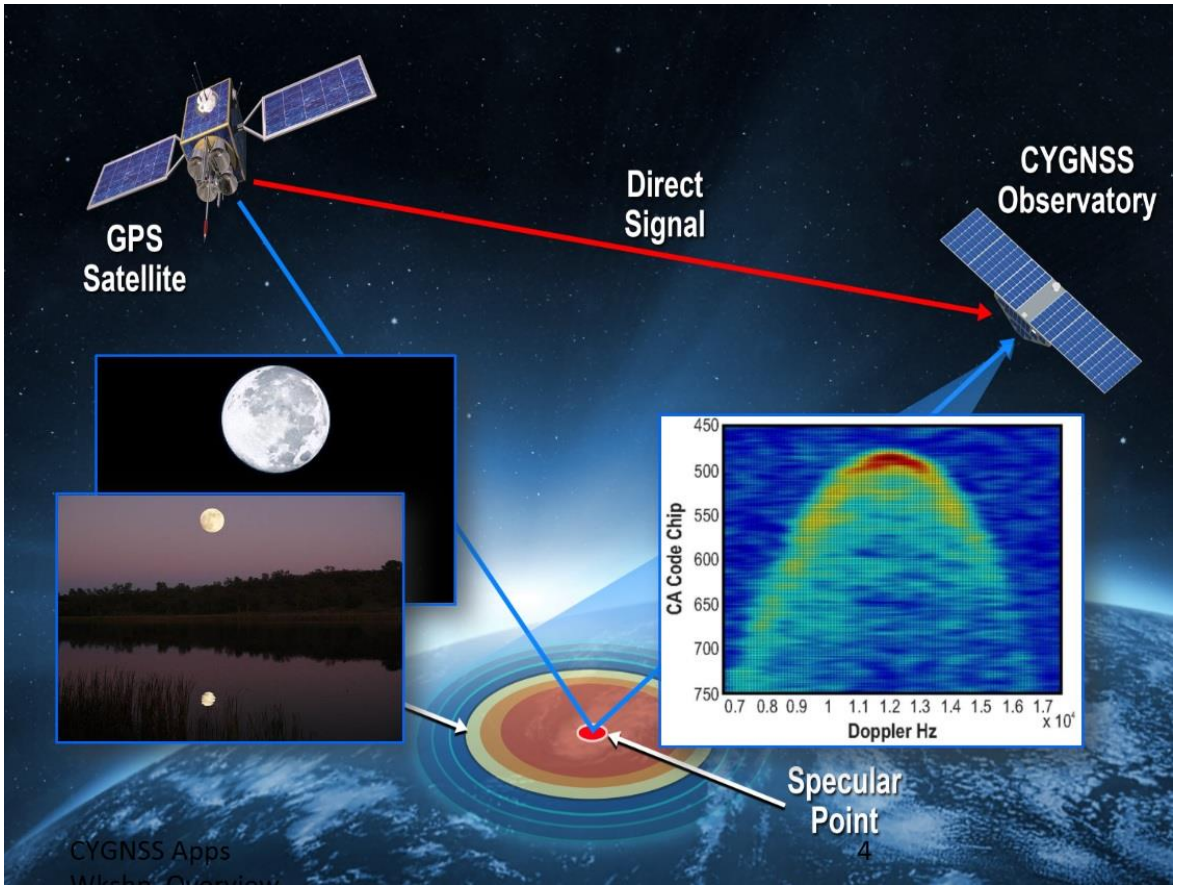


Photo credit: CYGNSS

CYGNSS Science Mission

No.	Requirement	Baseline	Threshold
1	Wind speed dynamic range at 5 km × 5 km resolution	3–70 m s^{-1}	3–40 m s^{-1}
2	Operation in presence of rain	Yes	Same as baseline
3a	Retrieval uncertainty for winds > 20 m s^{-1}	10%	Same as baseline
3b	Retrieval uncertainty for winds < 20 m s^{-1}	2 m s^{-1}	Same as baseline
3c	Spatial resolution	25 km × 25 km or better	50 km × 50 km or better
4a	100% duty cycle during science operations	Yes	Same as baseline
4b	Mean temporal resolution	<12 h	Same as baseline
4c	Spatial sampling coverage of cyclone historical tracks in 24 h	70%	50%
5	Calibrate and validate CYGNSS data in individual wind speed bins above and below 20 m s^{-1}	Yes	Same as baseline
6	Support operational hurricane forecast community	Yes	Same as baseline

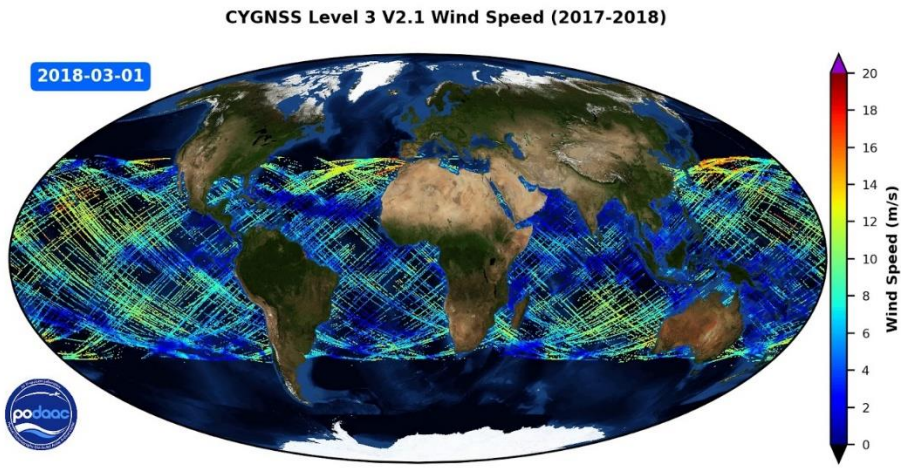


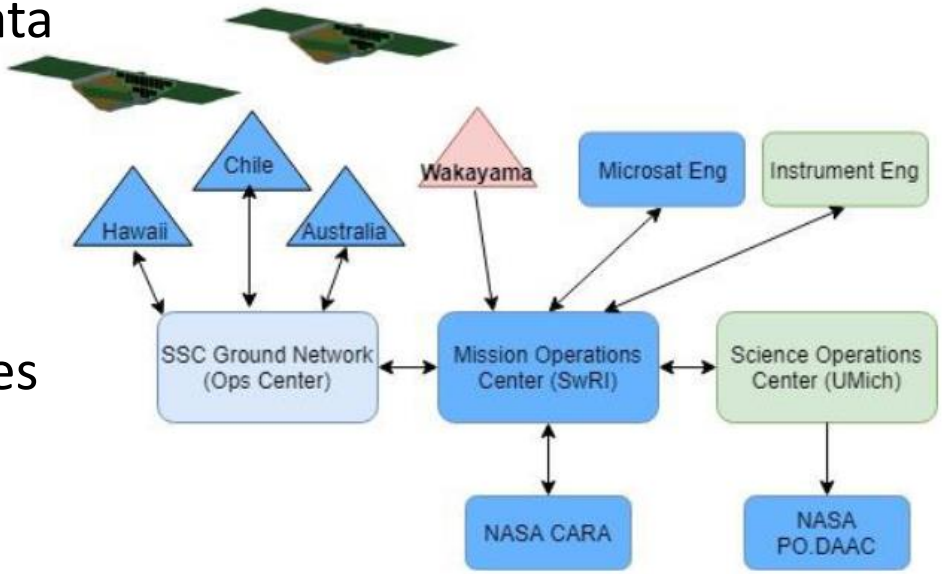
Photo credit: CYGNSS

CYGNSS Science collections

- S/C constantly collect data via windowed Delay Doppler Maps (DDMs) at 2 Hz, resulting in
- ~100 flash blocks (256-KB each) of engineering data
- ~1000 flash blocks of science data to downlink each day

- We downlink to SSC ground stations over Australia, Chile or Hawaii in appx. 10-minute passes
  - 1 per S/C per day

- SOC requests special science collections:
  - Raw IF (intermediate frequency)
  - Full (non-windowed DDM)



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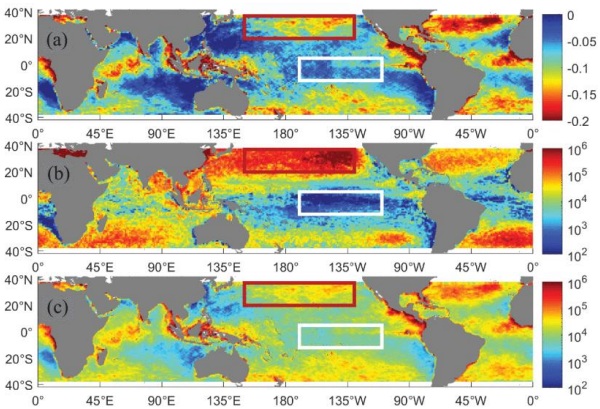
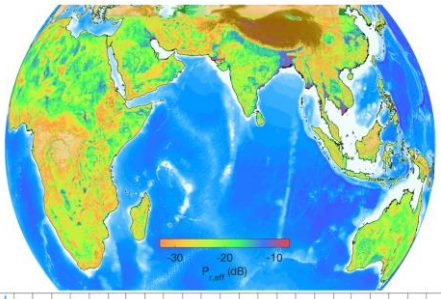
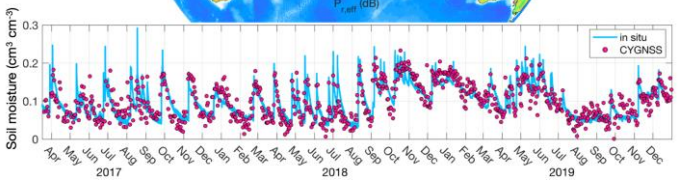
Increased special science interest and collections

Since launch, CYGNSS data has been used for these additional purposes:

- Ocean surface heat flux
- Freeze/thaw transitions
- Flood inundation
- Soil moisture
- Microplastics







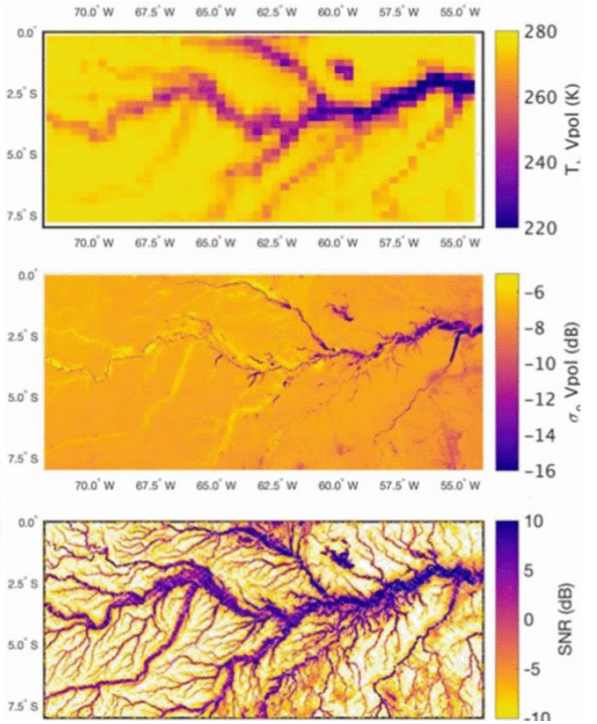
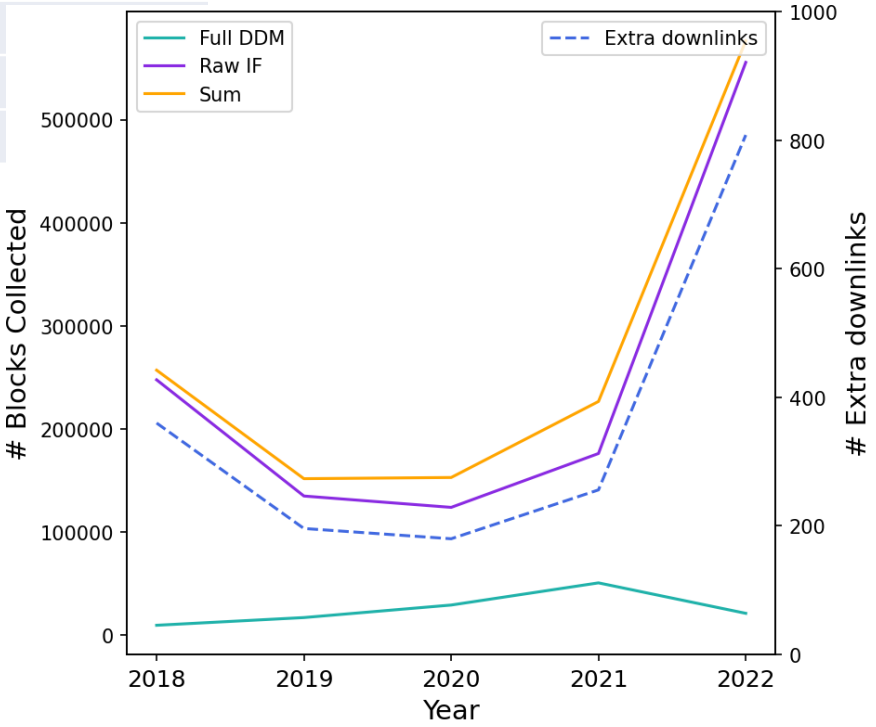


Photo credit: Evans & Ruff, 2021; Chew & Small, 2020; Ruf et al. 2022

More special science collects = more downlinks

Year	Normal science downlinks	Special Raw downlinks
2018	1733	272
2019	3187	85
2020	3061	192
2021	3013	287
2022	3095	790

- For each 60 second Raw IF collection, ~ 2750 blocks are recorded
  - 4 additional Raw downlinks must be added to the schedule to downlink the collection
- On average, 4 Raw IF collects per week plus additional Raw IF and/or Full for cyclone or flooding activities



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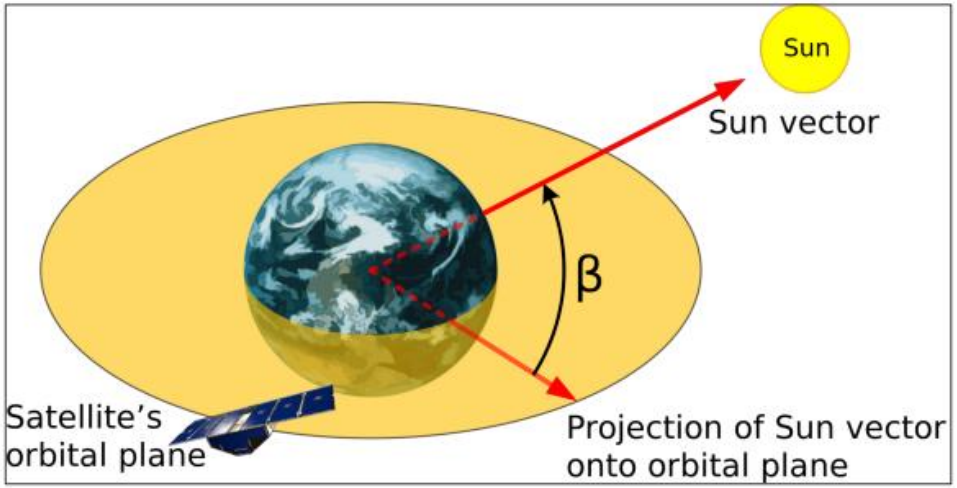
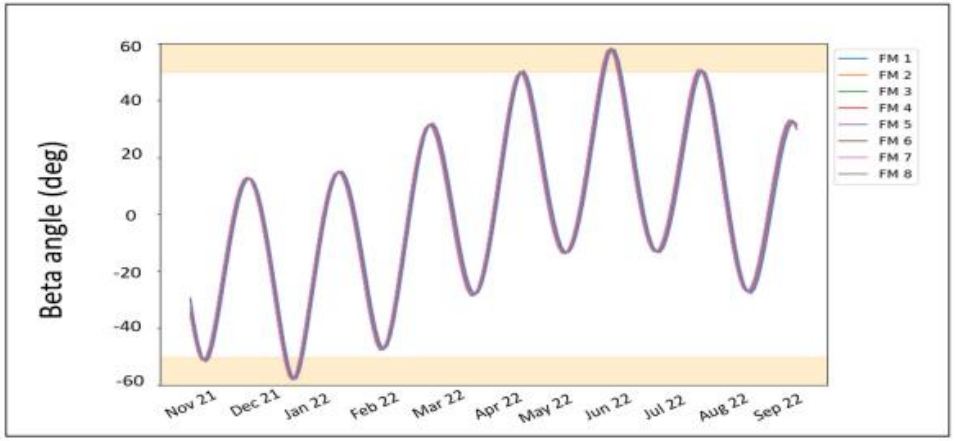
Beta angle as a result of low orbit and inclination





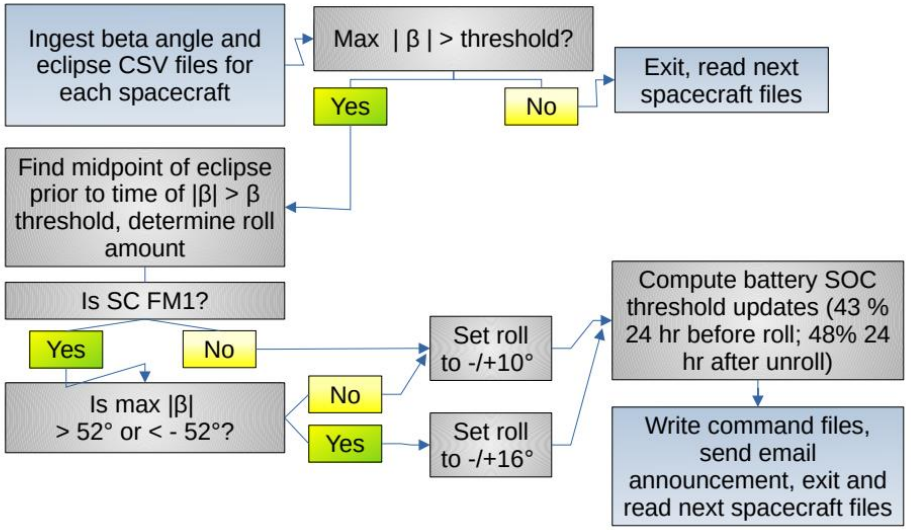
Early mission threshold estimations

- Before launch and early-on in the mission the following were estimated to accommodate reduced power generation when beta angle is high:
  - S/C battery usage
  - solar array power generation
  - Maximum |β| (roll threshold) before battery SoC hits 48% (loadshed threshold)

- When beta angle exceeds roll threshold, affected S/C roll toward the Sun to increase power generation and to prevent battery loadshed
  - S/C roll by updating quaternians and mode commands uploaded via ATS
  - S/C battery loadshed threshold is also reduced by 5%
  - S/C onboard RTS 3 is updated to tell s/c expected pointing and mode as a rolled state in the event of a reboot

Predicting upcoming BA seasons

- We have developed a python script to analyze STK output of beta angle predictions to notify the CYGNSS team when the beta angle is getting high, and S/C will need to roll toward the sun



Subject **[CYGNSS_MOC] Automated notification of upcoming BA season**

[CYGNSS] Automated Message....

	BA Season Start	BA Season End	Max BA	Roll Type	SOC to 43	Roll time	Unroll time	SOC to 48
F7	12-04-2022 21:00:00	12-21-2022 18:30:00	-58.116	16	12-03-2022 20:14:13	12-04-2022 20:14:13	12-21-2022 20:21:28	12-22-2022 20:21:28
F9	12-06-2022 09:30:00	12-16-2022 22:00:00	-58.000	10	12-05-2022 09:06:21	12-06-2022 09:06:21	12-16-2022 23:43:05	12-17-2022 23:43:05
2B	12-06-2022 03:30:00	12-16-2022 15:30:00	-57.975	10	12-05-2022 02:03:24	12-06-2022 02:03:24	12-16-2022 16:40:53	12-17-2022 16:40:53
2C	12-06-2022 02:00:00	12-16-2022 14:30:00	-57.965	10	12-05-2022 01:32:21	12-06-2022 01:32:21	12-16-2022 16:09:31	12-17-2022 16:09:31
2F	12-07-2022 15:30:00	12-18-2022 05:30:00	-58.094	10	12-06-2022 14:04:40	12-07-2022 14:04:40	12-18-2022 06:22:21	12-19-2022 06:22:21
36	12-06-2022 05:00:00	12-16-2022 17:30:00	-57.985	10	12-05-2022 03:51:32	12-06-2022 03:51:32	12-16-2022 18:28:23	12-17-2022 18:28:23
37	12-06-2022 01:30:00	12-16-2022 13:30:00	-57.964	10	12-05-2022 00:30:45	12-06-2022 00:30:45	12-16-2022 15:08:14	12-17-2022 15:08:14
49	12-06-2022 22:00:00	12-17-2022 11:00:00	-58.031	10	12-05-2022 21:11:47	12-06-2022 21:11:47	12-17-2022 11:51:47	12-18-2022 11:51:47

Command files written to: */home/cygnss/PlanningPersonnelInterface/SIMPLCode/Input/*

Command files: ['CYGNSS_F7_MOC_CMD_2022_318_16_53_25.txt', 'CYGNSS_F9_MOC_CMD_2022_318_16_53_25.txt', 'CYGNSS_2B_MOC_CMD_2022_318_16_53_25.txt', 'CYGNSS_2C_MOC_CMD_2022_318_16_53_25.txt', 'CYGNSS_2F_MOC_CMD_2022_318_16_53_25.txt', 'CYGNSS_36_MOC_CMD_2022_318_16_53_25.txt', 'CYGNSS_37_MOC_CMD_2022_318_16_53_25.txt', 'CYGNSS_49_MOC_CMD_2022_318_16_53_25.txt']

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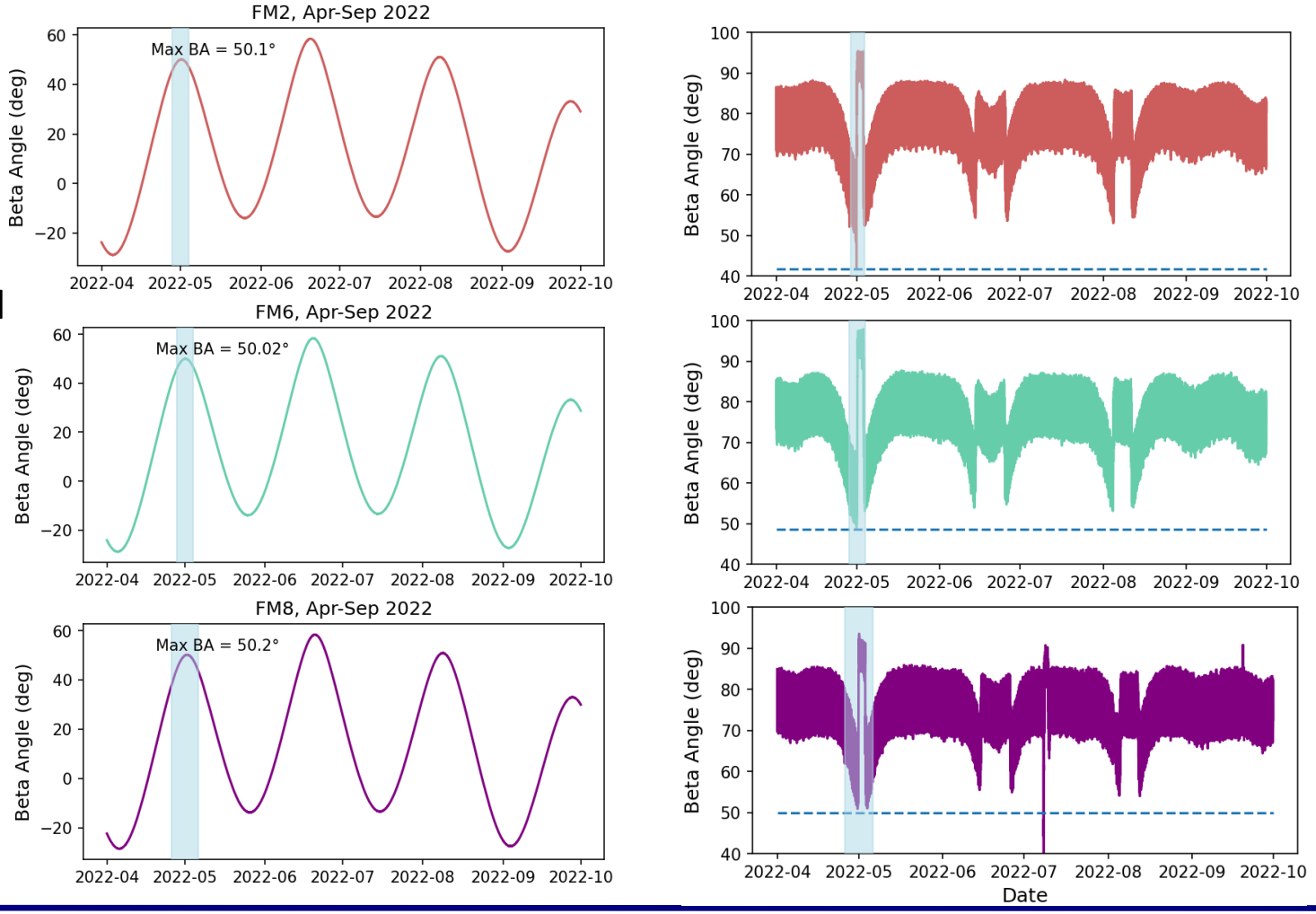
Early mission beta angle threshold no longer sufficient for all S/C – a triple safing in May 2022

(Roll threshold = 50.8°)



Revised beta angle thresholds for all S/C

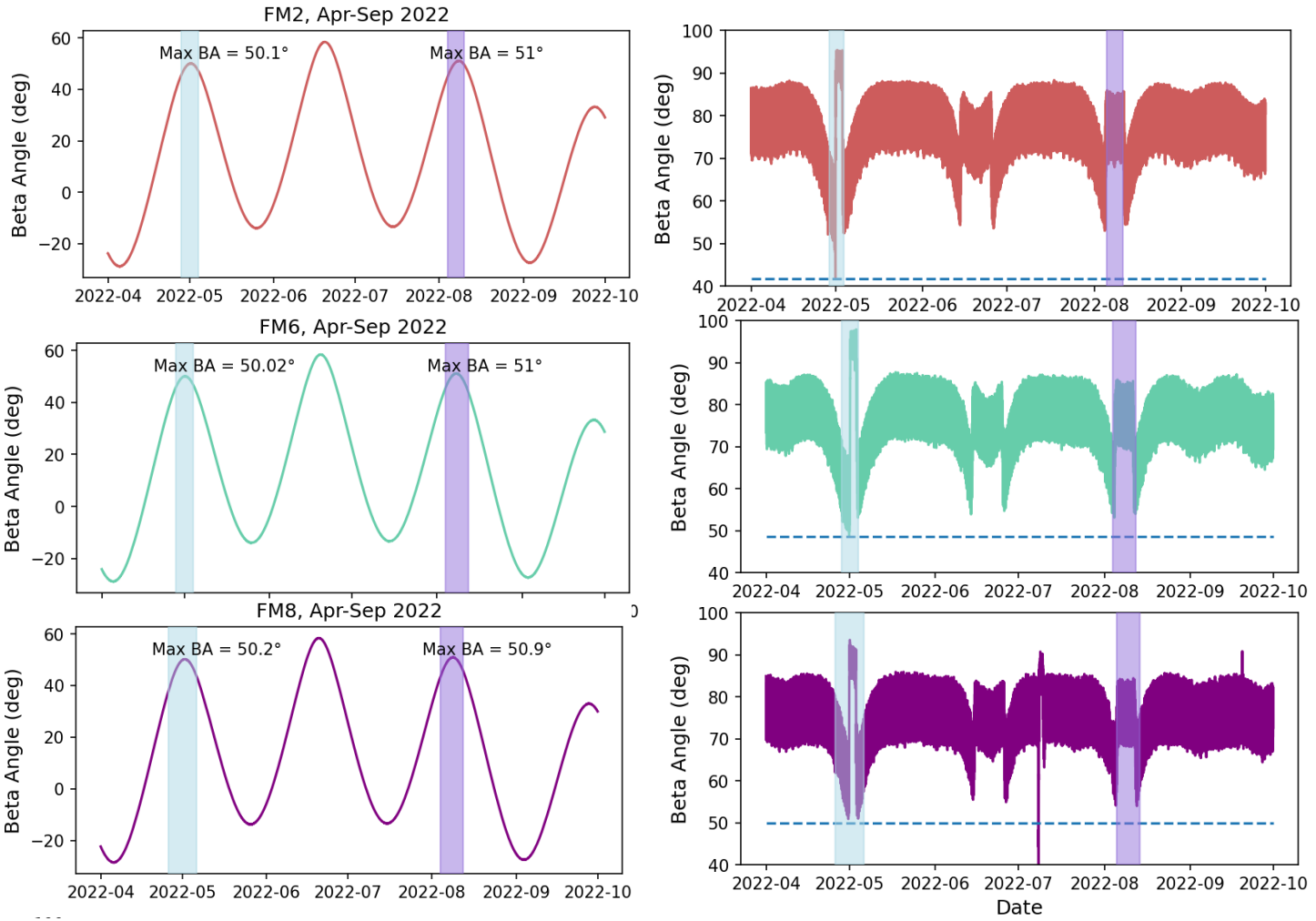
Following the triple-safing in May, we re-assessed power usage, power generation and beta angle data for all S/C when Earth-Sun distance is maximum (aphelion)

- New roll threshold found to be 40.8° for FM 1 and 50.8° for the other 7 S/C
- We also adding new roll phase of 16° toward the sun for FM1

FM	Old beta angle threshold (+/- deg)	Revised beta angle threshold (+/- deg)	Roll amount (-/+ deg)
1	40.8	34.5 (52.0)	10 (16)
2	50.8	47.0	10
3	50.8	47.0	10
4	50.8	47.0	10
5	50.8	47.0	10
6	50.8	47.0	10
7	50.8	47.0	10
8	50.5	47.0	10

After the revised roll threshold – looking at August 2022 beta angle season

(Roll threshold = 40.8°)



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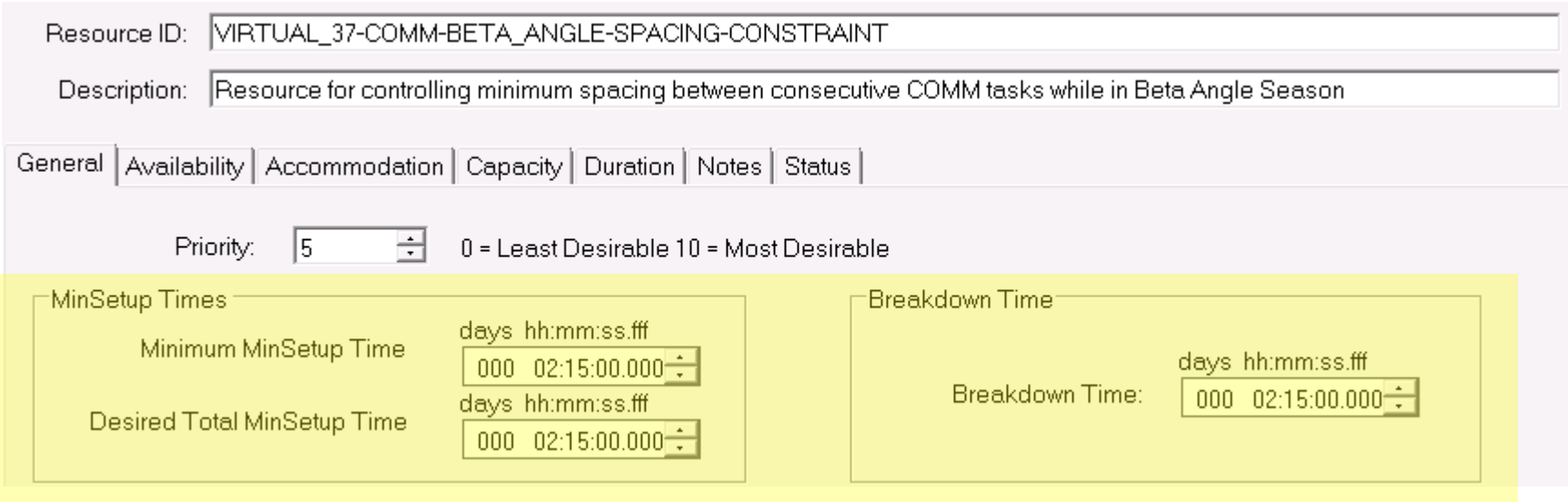
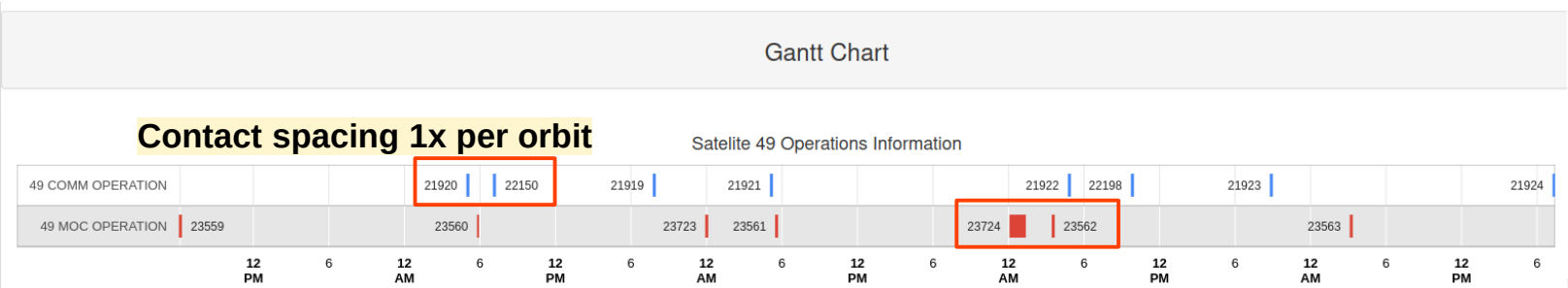
Spacing out downlinks during high beta seasons

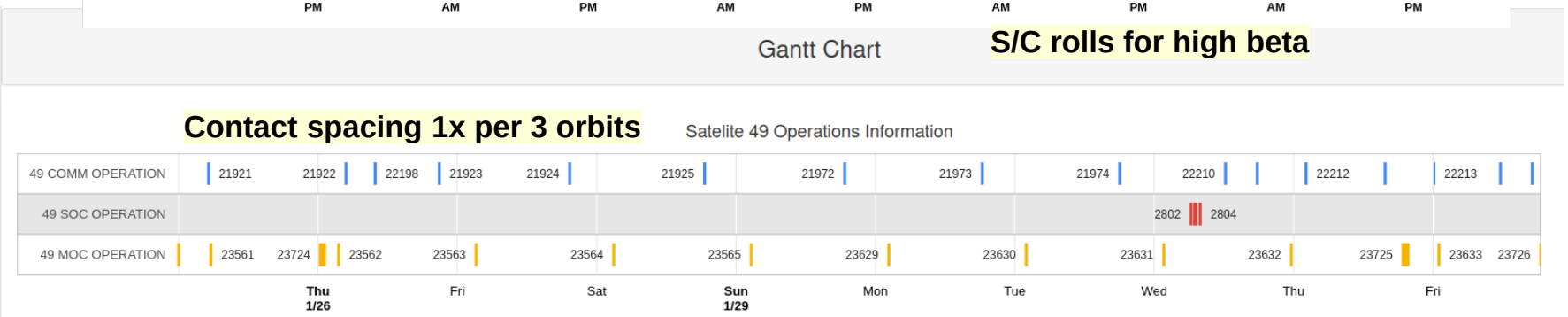
- For planning, we utilize the SIMPL software coupled with STK and Orbit Logic's STK Scheduler
- We modified SIMPL to automatically space out contact requests to once per 3 orbits (normal is once per orbit) when the new beta angle flag is activated



Spacing out downlinks during high beta seasons

- Shown below is the scheduled spacing for COMM tasks before S/C roll, the MOC task for roll, and COMM task spacing after roll





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Accounting for gaps in data on Raw IF collections and downlinks

- Many downlinks result in some gaps in data due to occasional glitches in connectivity between the S/C transceiver and ground station antenna, masking of the ground station antenna, or inclement
- weather conditions at the ground station

- Gap = non-sequential jump in sequence count of packets received intact on the ground

- We have a script the automatically checks each hour for gaps in recently processed data – this script writes to a proc file that is called automatically 2 minutes before the end of each S/C contact to replay any missing data

--- SC2F ---

Start_Time	Start_Block	Replay_Length	Percent_Recovered
2023-01-29 18:04:09	416	2	0.657%
2023-01-30 07:19:45	7169	1	0.283%
2023-02-01 11:41:30	5441	1	0.078%
2023-02-01 17:07:42	255	2	0.315%
2023-02-02 04:43:59	308	2	0.032%
2023-02-02 15:08:02	356	2	0.672%
2023-02-02 16:31:59	6185	1	0.162%
2023-02-02 16:45:56	6191	2	0.528%
2023-02-03 13:04:58	6708	2	0.173%

--- SC37 ---

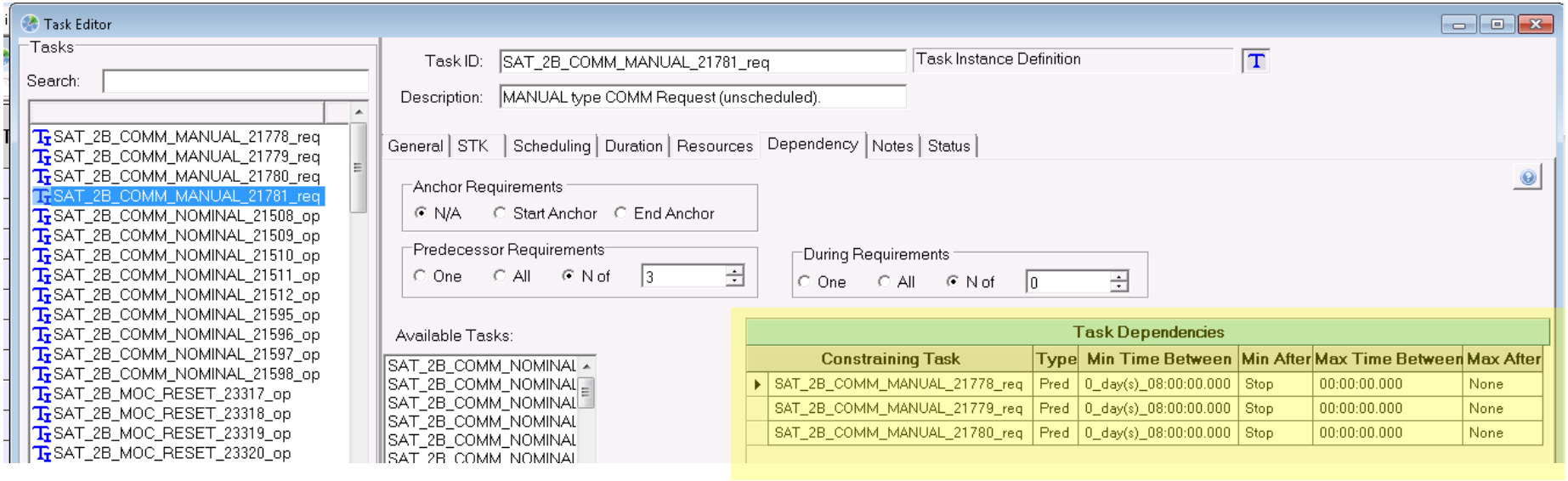
Start_Time	Start_Block	Replay_Length	Percent_Recovered
2023-01-29 19:36:23	6658	2	0.383%
2023-01-29 19:38:04	145	2	0.212%
2023-01-30 05:53:21	6926	2	0.359%
2023-01-31 18:59:01	363	2	0.420%
2023-02-01 18:39:21	471	2	0.282%
2023-02-02 00:36:59	5563	1	0.173%
2023-02-02 23:50:01	6162	2	0.724%
2023-02-03 00:55:06	6190	2	0.447%

--- SC49 ---

Start_Time	Start_Block	Replay_Length	Percent_Recovered
2023-01-29 18:47:39	328	2	0.308%
2023-01-30 07:11:23	7476	1	0.352%
2023-01-31 03:52:16	478	2	0.119%
2023-02-01 06:58:11	13282	1	0.001%
2023-02-01 07:24:28	5624	2	0.173%
2023-02-01 07:45:08	14512	2	0.004%
2023-02-01 07:50:27	14753	1	0.001%
2023-02-01 08:09:08	5632	2	0.173%
2023-02-01 16:45:24	5858	2	0.145%
2023-02-01 17:50:02	167	2	0.669%
2023-02-02 02:04:37	205	2	0.656%
2023-02-02 19:55:58	6552	1	0.174%
2023-02-03 11:42:45	304	55	10.286%
2023-02-03 11:46:05	6664	300	11.425%

Space out last Raw IF downlink by 8 hours

We modified SIMPL such that for a new set of manual requests, the last ID (typically the 4th) generated is dependent on the previous 3 such that it must be scheduled at least 8 hours after the third



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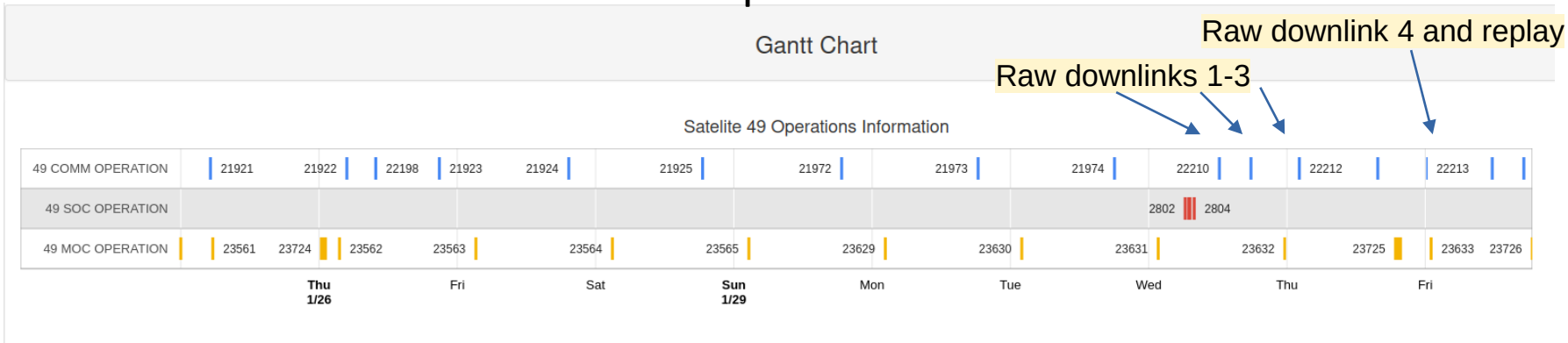
- We modified SIMPL such that for a new set of manual requests, the last ID (typically the 4th) generated is dependent on the previous 3 such that it must be scheduled at least 8 hours after the third

- Below is the resulting GANTT chart illustrating the spacing of a scheduled Raw IF downlink sequence



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In summary, we have:

- Revised the roll threshold for all S/C and roll amount for FM1 following an annual review in 2022 and a triple-safing event in May 2022
- Implemented software to automatically
  - check and notify of upcoming high beta angle seasons
  - space out contacts with S/C to once every three orbits during high beta angle seasons
  - space out the last Raw IF downlink to allow for data processing and gap calculations

These changes have reduced the risk of a S/C safing and increased the amount of science downlinked on a weekly basis all while reducing the time spent on mission planning